Shallow Water MCM and ASW Using Off-Board, Autonomous Sensor Networks and Multistatic, Time-Reversal Acoustics

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LONG-TERM GOALS

To achieve robust multi-static detection and classification of mine-like objects using cooperative networks of virtual acoustic sensors.

OBJECTIVES

To utilize high fidelity acoustic modeling of both scatterers and shallow-water environments to better understand and bound the limits of detectability for mine-like objects via autonomous networks of sensors. To conduct a series of realistic experiments using multiple sonar-equipped AUVs in shallow water and then cross-validate the results obtained with high precision modeling and visualization. To better understand the problems of cooperative autonomous vehicle interaction to define the base-line infrastructure requirements for cooperative detection, classification and navigation.

APPROACH

This program couples high accuracy acoustic modeling and visualization with customized AUV technology. The sonar sensing uses the bi-static and multi-static Synthetic Aperture created by the network, in combination with medium frequency (4-24 kHz) wide-beam insonification to provide coverage, bottom penetration and location resolution for concurrent detection, localization and classification of proud and buried targets in SW and VSW. The signal processing effort in SWAMSI is therefore centered around generalizing SAS processing to bi-static and multi-static configurations, including bi-static generalizations of auto-focusing and track-before-detect (TBD) algorithms. Another issue concerns the stability and coherence of surface and seabed multiples and their potential use in advanced medium-frequency sonar concepts.

MIT's acoustic modeling capabilities derive from both the SEALAB suite (VASA Associates) for general shallow water acoustics and FEMLAB (COMSOL Inc) for detailed structural acoustics and

1

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14. ABSTRACT
To utilize high fidelity acoustic modeling of both scatterers and shallow-water environments to better understand and bound the limits of detectability for mine-like objects via autonomous networks of sensors. To conduct a series of realistic experiments using multiple sonar-equipped AUVs in shallow water and then cross-validate the results obtained with high precision modeling and visualization. To better understand the problems of cooperative autonomous vehicle interaction to define the base-line infrastructure requirements for cooperative detection, classification and navigation.

15. SUBJECT TERMS

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target modeling. SEALAB incorporates the OASES environmental acoustic modeling framework developed at MIT [1,3], which is a widely distributed suite of models covering a variety of ocean waveguide and source/receiver representations. Recent developments are computational modules for full wave theory modeling of mono-static and bi-static target scattering and reverberation in shallow water waveguides. The most recently developed module, OASES-3D provides wave-theory modeling of the full 3-D acoustic environment associated with mono-static and bi-static configurations in SW and VSW with aspect-dependent targets and reverberation features [2,3]. It incorporates environmental acoustic features specifically associated with bi-static sonar concepts in shallow water, including aspect-dependent target models, seabed porosity, and scattering from anisotropic seabed roughness such as sand ripples.

With every major AUV deployment, the Mission Oriented Operating Suite (MOOS) previously created at MIT by research engineer Paul Newman advances in robustness and flexibility, and has been undergoing major upgrades in regard to the behavior-based control using the new IvP-Helm developed by Mike Benjamin of NUWC, who works closely with the MIT team as a Visiting Scientist. Another significant component is the development of a comprehensive simulation testbed, coupling the MOOS-IvP autonomous vehicle simulation environment with the SEALAB high-fidelity acoustic simulator, resulting in a complete, distributed software base for planning, simulating and analyzing multi-vehicle MCM missions.

WORK COMPLETED

Concurrent Detection, Classification and Localization using Time-reversal

A large part of our efforts has been devoted to evaluating the potential of using a monostatic configuration to achieve target DCL based on a time reversal mirror approach. This would involve using a low frequency projector mounted on an AUV while having it tow a horizontal array of receivers.

The technique envisioned involves low frequency insonification of a flush-buried target (GOATS) at subcritical and supercritical angles. The resulting scattered field measured by the receiving array is then time reversed to simulate onboard the AUV its back propagation from each receiver to the seabed. The superposition of the fields generated by each receiver on the seabed results in a map that indicates regions where acoustic energy emerged after the target was insonified (thus indicating the target location). This analysis is repeated for successive locations of the source and array orientations. It is also restricted to the resonant frequencies of the man-made target to limit unwanted back propagations to clutter possibly present on the seabed.

A specific 3D model has been developed based on an existing 2D model to explore this technique and to investigate the conditions (array element spacing, array depth, orientation relative to the target) under which a clear retrofocus can be achieved on the seabed. The 3D model produces the scattered field at each element of the receiving array by convolving the incident field with the target response. The transfer functions computed from each receiver to any location on the seabed are then convolved with the time reversed version of the scattered signal previously measured at the receivers location to compute the resulting backpropagated field on the seabed.
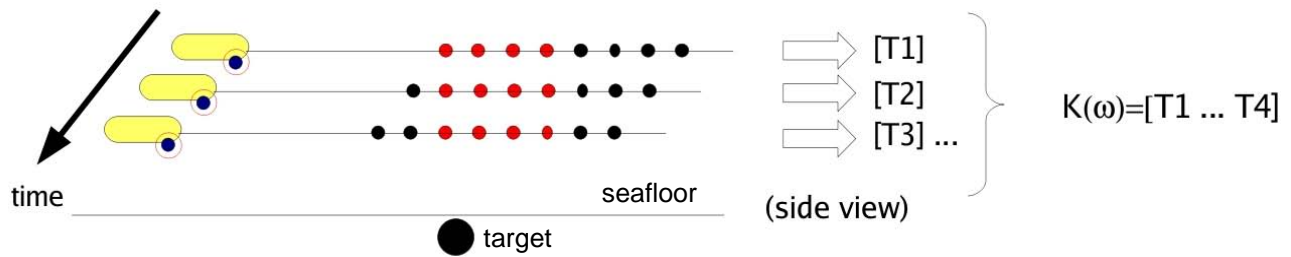
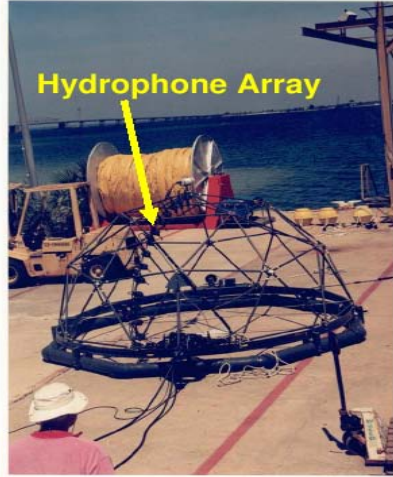*Fig. 1. Construction of the transfer matrix from successive measurements*

Successive insonification and scattering measurements (FIG. 1) are also used to store the complex pressures measured by each receiver of an artificially stationary section of the array in order to construct the transfer matrix K for singular value extraction. Simulations have also been conducted to investigate the number of singular values resolvable as a function of array orientation and element spacing.

EVA'06 Experiment

Fig. 2. NRL-SSC Dome array for near-field scattering measurements

A major effort was undertaken in collaboration with NURC on the execution of the EVA'06 experiment at Marciana Marina, Italy. The objective of this experiment is to provide an extensive 3-dimensional data set for bi-static scattering from proud and partially buried complex targets. Thus, the experiment used the TOPAS parametric source for controlled insonification of the targets, in combination with an extensive receiver suite, including a small bi-static array synthetic aperture below the R/V Leonardo, and a dome array deployed by NRL-Stennis allowing for 3-D measurement of the scattering in the near-field of the targets. In addition to providing a unique data set for validation of the

3

new target scattering models developed jointly between MIT and NURC, the experiment also explored the possibility of using synthetic-aperture, time-reversal acoustics for target classification.

The MIT analysis effort is focusing on the near-field data set obtained on the dome array. Figure 2 shows the detailed specification of the array.

RESULTS

Concurrent Detection, Classification and Localization using Time-reversal

Simulations have shown the effects of azimuth angle on the number of singular values resolvable varies with azimuth angle and on the amplitude of singular values resolved as shown in Fig. 3.
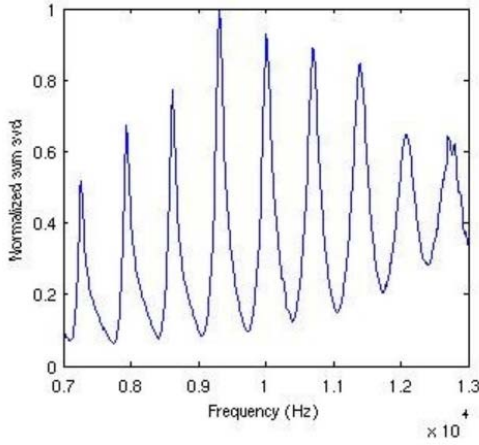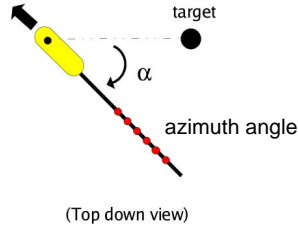

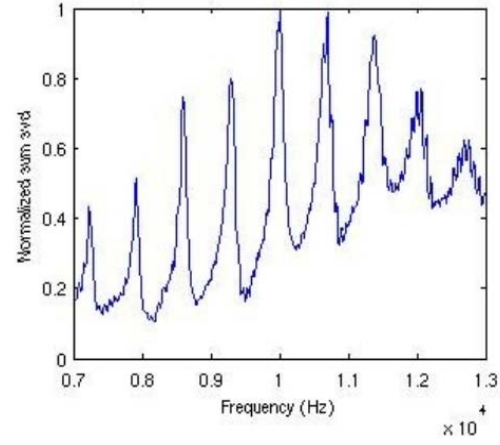*Fig. 3-A. Normalized sum of singular values for azimuth angle of 10 degrees*   *Fig. 3-B. Normalized sum of singular values for azimuth angle of 40 degrees*
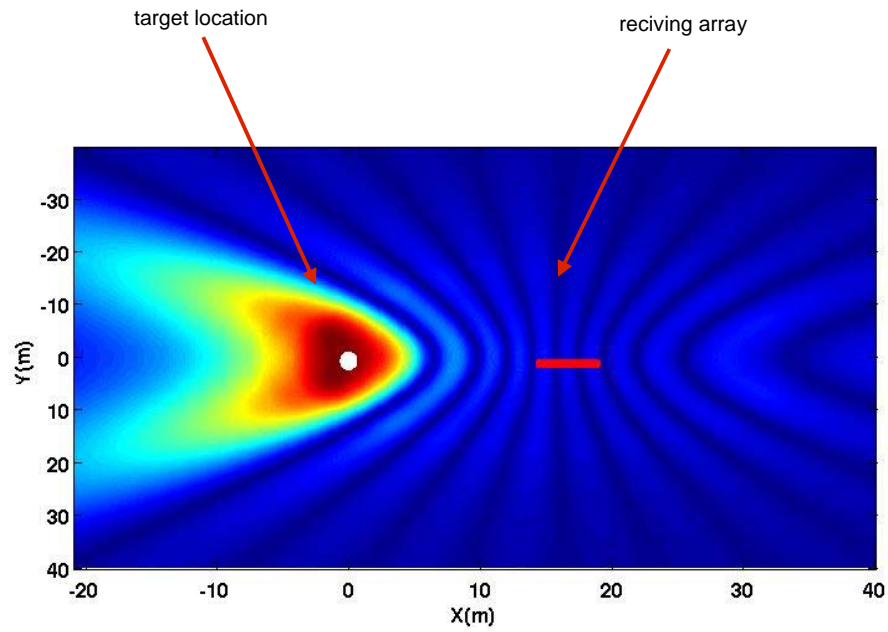
**Fig. 4. Pressure amplitude on the seabed after backpropagation of the
time reversed scattered signal from the receiving array**

The flush buried target (spherical shell of diameter 1m) is insonified from a source located 10m above
the seabed at (x,y)=(10,0). The back propagation of the time reversed scattered signal from the
receiving array (12 receivers) to the seabed (FIG3) is simulated at a frequency of 7.3kHz. The resulting
pressure amplitude on the seabed shows a maximum in the vicinity of the target location (x,y)=(0,0).
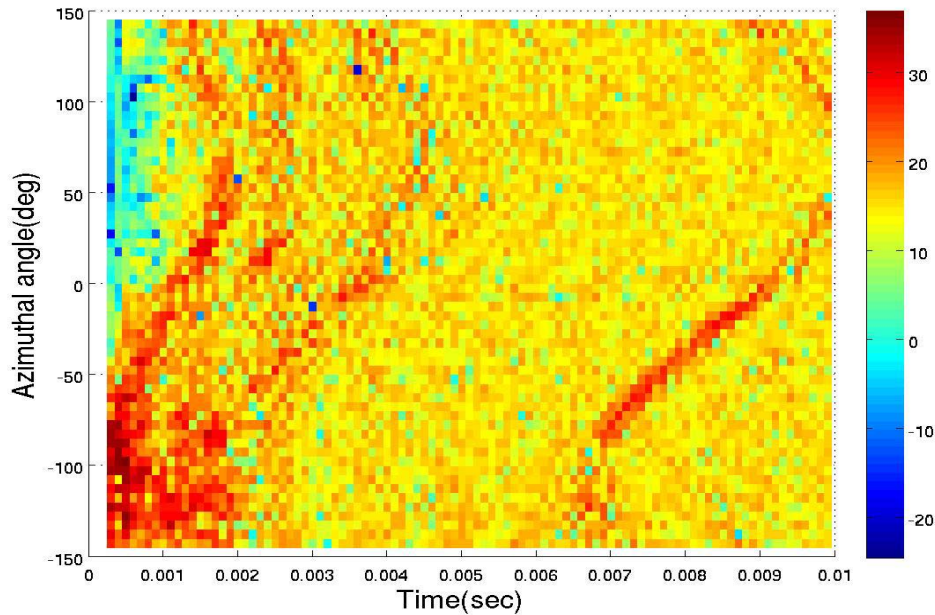
EVA'06 Experiment

**Fig. 5: Frequency averaged magnitude of short time Fourier transform in dB plotted as
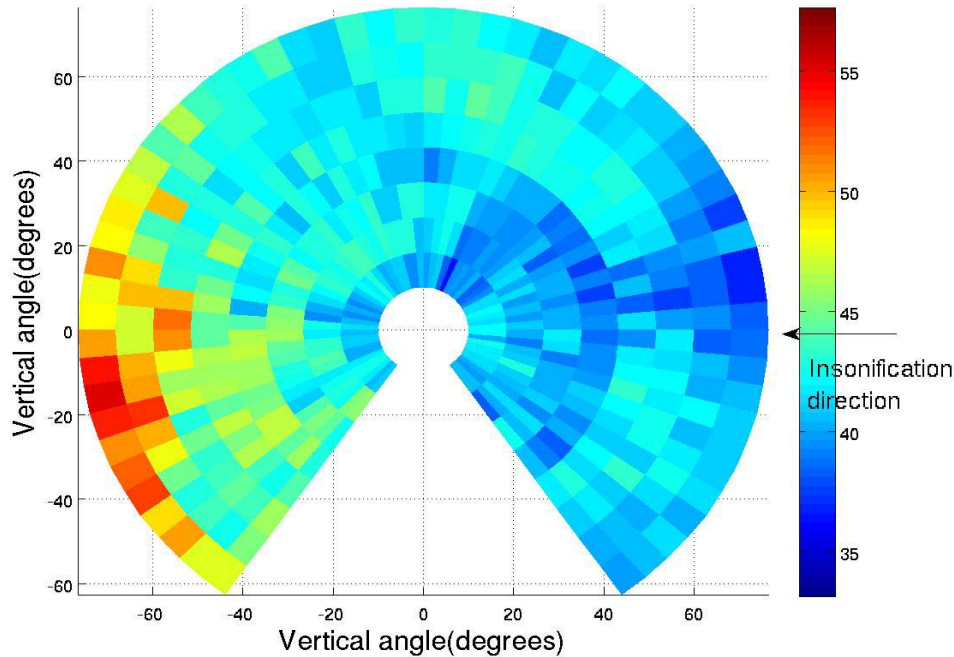a function of azimuth angle and discrete time steps for channel 3**

5

Fig. 6: Dome Mapping of average intensities in dB as a function of azimuth and vertical angles at frequency 10,000Hz

Figure 5 shows therequency averaged magnitude of a short time Fourier transform in dB plotted as a function of azimuth angle and discrete time steps for channel 3 The different bands correspond to arrivals of specular echo, Lamb waves, signal from scattering by the back side of the cage and a rock on the seabed which was behind the target. Figure 6 shows a contour plot of the intensity measured versus the vertical, polar angle (radius) and azimuth. The figure clearly shows that maximum intensity happens to be in the forward scattering region as expected. The interpretation is currently being performed using OASES and AXISCAT.

IMPACT/APPLICATIONS

The long-term impact of this effort is the development of new sonar concepts for VSW MCM, which take optimum advantage of mobility, autonomy and adaptivity. For example, bi-static and multi-static, medium-frequency sonar configurations are being explored for completely or partially proud or buried mines in shallow water, with the traditional high-resolution acoustic imaging being replaced by a 3-D acoustic field characterization as a combined detection and classification paradigm, exploring spatial and temporal characteristics which uniquely define the target and its environment.

TRANSITIONS

The virtual source modeling approach developed under this project [10] has been transitioned to NURC as part of the OASE3D target modeling framework. Here it ist has is coupled to the FEMLAB finite element framework to allow modeling of complex elastic targets. It has also been transitioned to NUWC (J. Blottman), CSS (D. Burnett), and WSU (Marston) for the same purpose. It is currently

being integrated with the MIT-MCM simulation framework developed under GOATS (N00014-05-1-0255) for simulating autonomous, adaptive target classification [7,8].

RELATED PROJECTS

This effort is closely related to the GOATS project, initiated as the GOATS'2000 Joint Research Project (JRP) with the NATO Undersea Research Centre (NURC), and continued at MIT under the GOATS'2005 grant (N00014-05-1-0255), funded jointly by ONR codes 321OA (Livingston), 321OE (Swean), and 321TS (Commander). The collaboration with NURC, is continued under the Hybrid Target Modeling and Focused Acoustic Field (FAF) Joint Research Projects (JRP).

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PUBLICATIONS

I. Lucifredi and H. Schmidt , "Sub-critical Scattering from Buried Elastic Shells". *J. Acoust. Soc. Am.,* 120, 3566-3583, 2006.

W. Luo and H. Schmidt, "Three-Dimensional Propagation and Scattering around a Conical Seamount," Submitted to *J. Acoust. Soc. Am.,* 2007.

K. Cockrell, H. Schmidt, "A proposed technique for source localization using an autonomous underwater vehicle," 153rd Meeting Acoustical Society of America, Salt Lake City, Utah, June 2007.

W. Luo and h. Schmidt, "Three-Dimensional Propagation and Scattering around a Conical Seamount," 153rd Meeting Acoustical Society of America, Salt Lake City, Utah, June 2007.

HONORS/AWARDS/PRIZES

K. Cockrell, Best student paper/young presenter award in Acoustical Oceanography: "A proposed technique for source localization using an autonomous underwater vehicle," 153rd Meeting Acoustical Society of America, Salt Lake City, Utah, June 2007.